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LATERAL HEAT FLOW EFFECTS ON THERMOGRAPHIC SENSITIVITY

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AIRCRAFT DIVISION, PATUXENT RIVER, MD

THE SECOND JOINT NASA/FAA/DoD
CONFERENCE ON AGING AIRCRAFT

August 31 - September 3, 1998

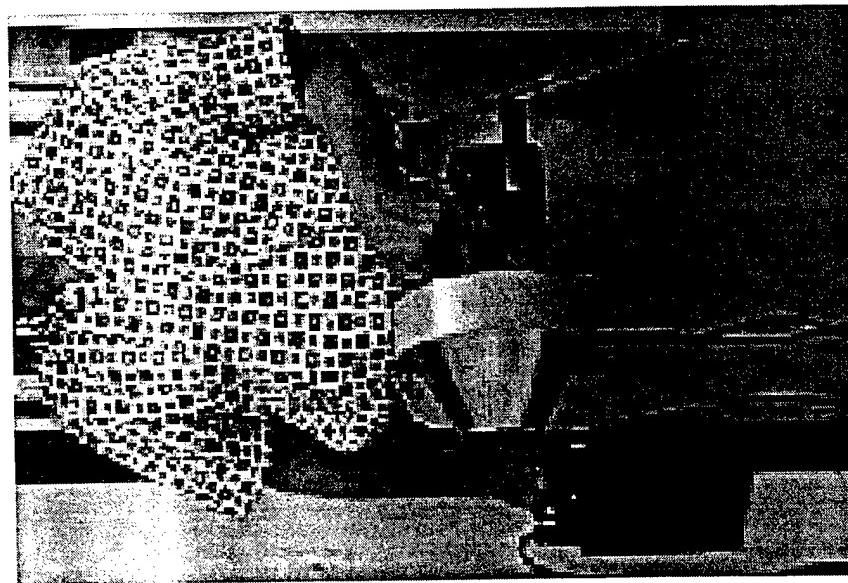
Williamsburg Marriott Hotel
Williamsburg VA

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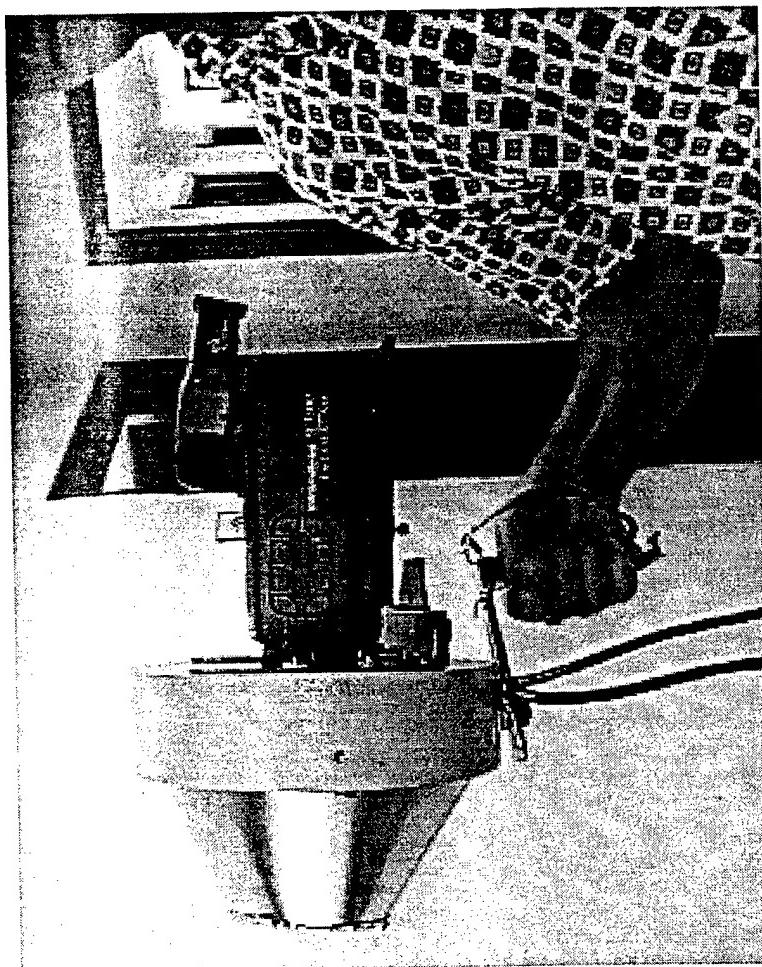
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PORTABLE IR CAMERA SYSTEM



AND POWER SUPPLY

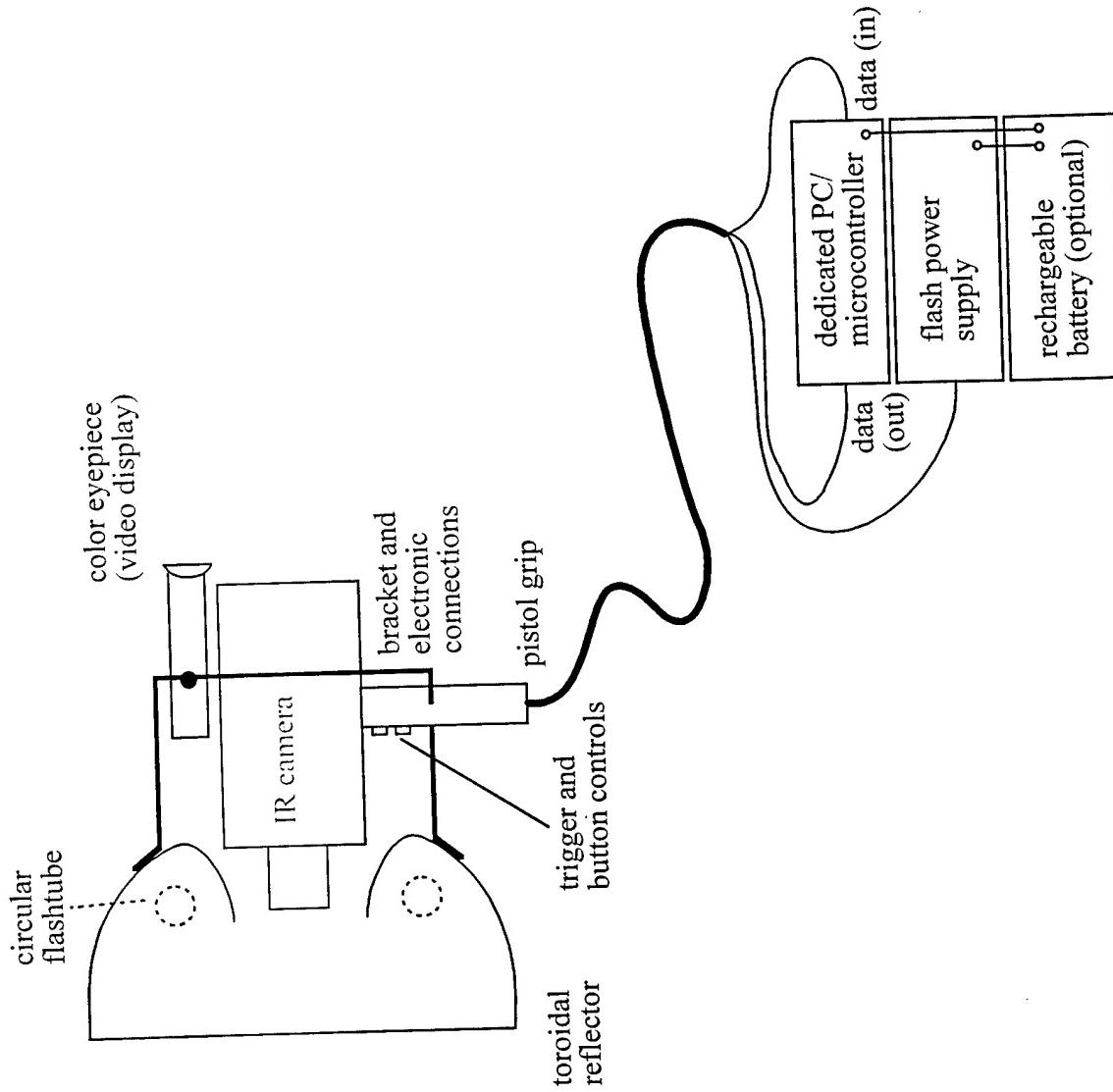


CAMERA HEAD

NAVAL AIR WARFARE CENTER, AIRCRAFT DIVISION, PATUXENT RIVER MD



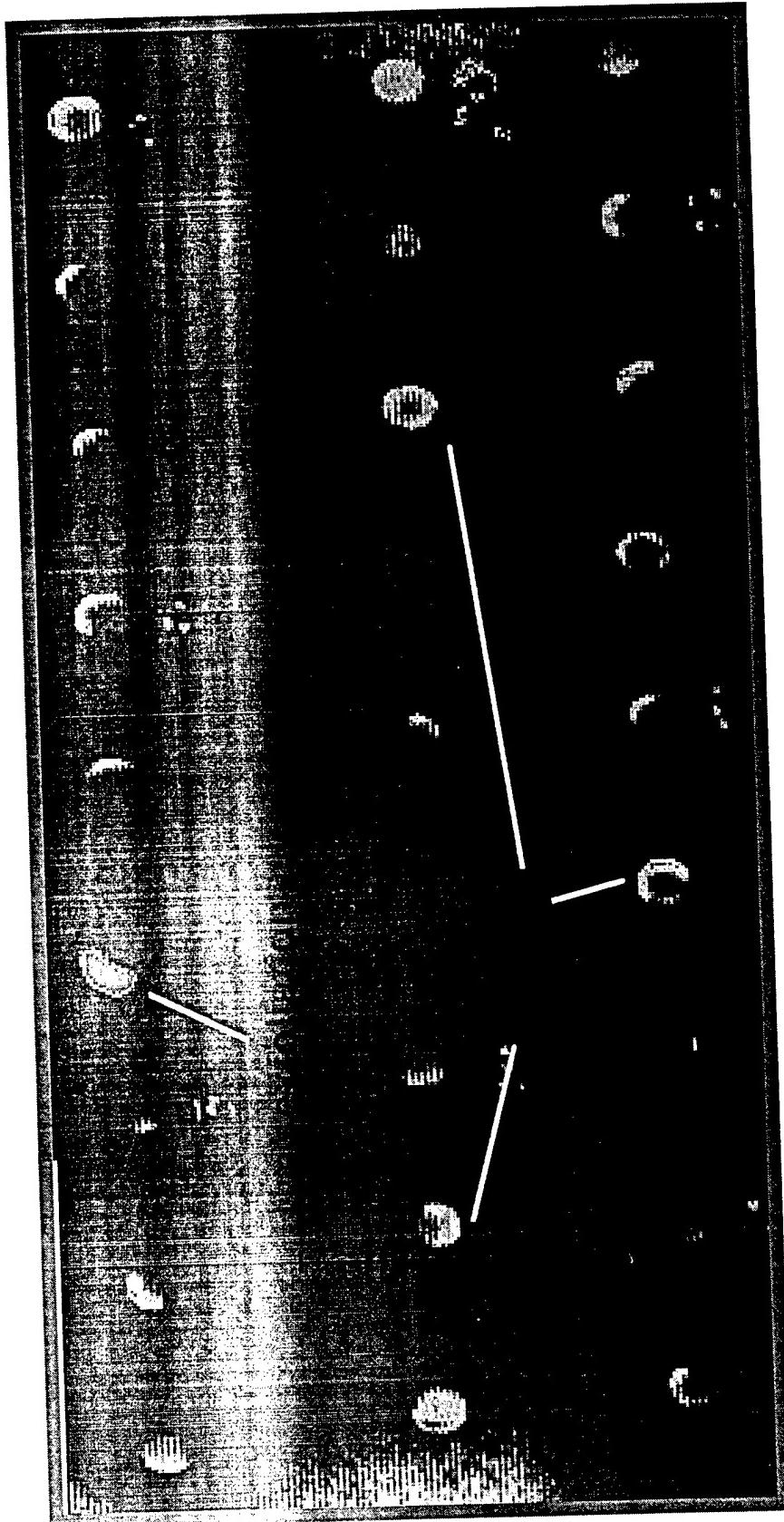
PORTABLE IR CAMERA SYSTEM





NAVAL AVIATION SYSTEMS

CORROSION DETECTION

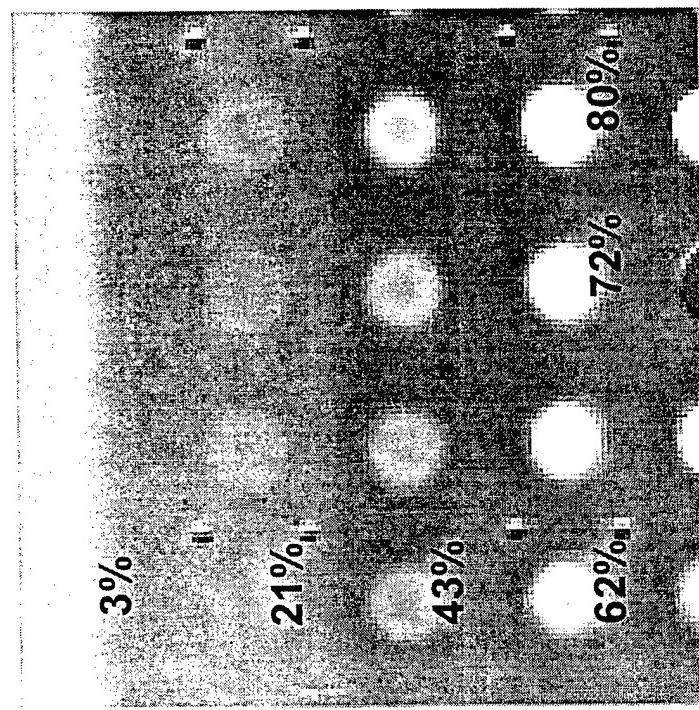


NAVAL AIR WARFARE CENTER, AIRCRAFT DIVISION, PATUXENT RIVER MD

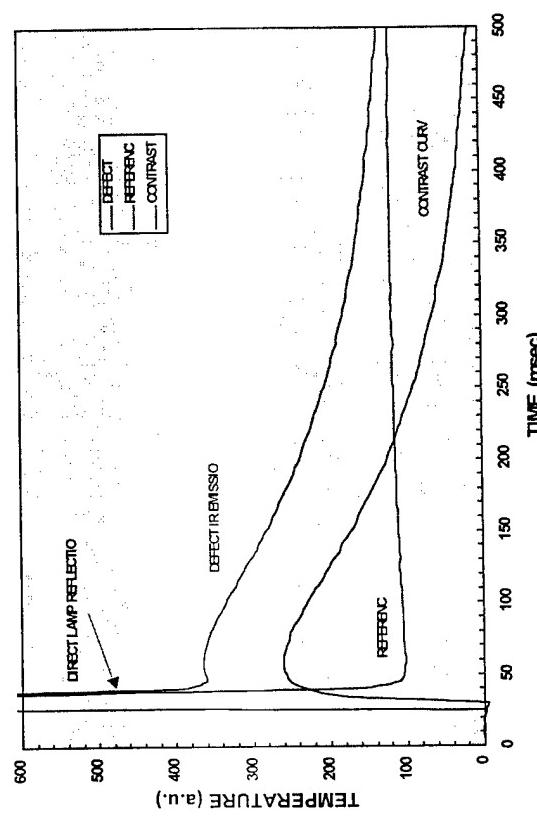


TEST PANEL & TYPICAL TIME-RESPONSE CURVES

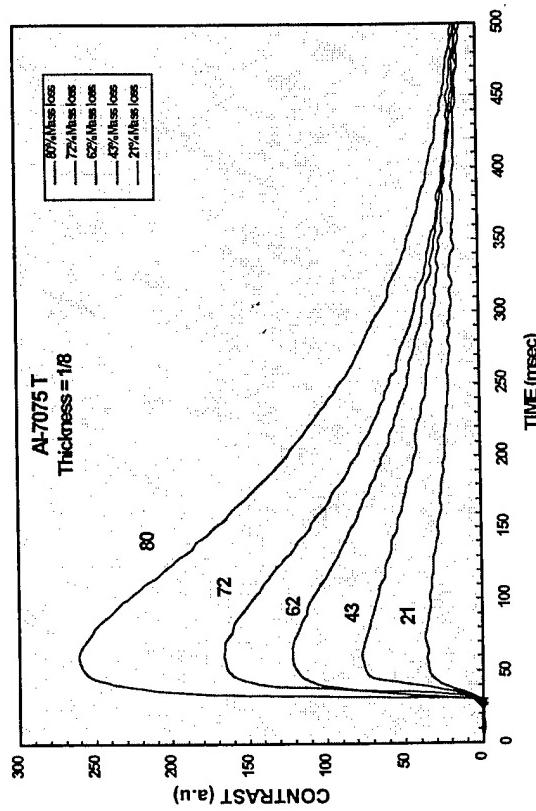
1/8" Thick Al-7075 panel



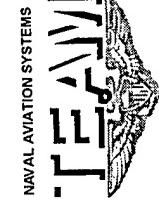
TEMPERATURE TIME SEQUENCE



CONTRAST CURVE



1" Diameter Holes

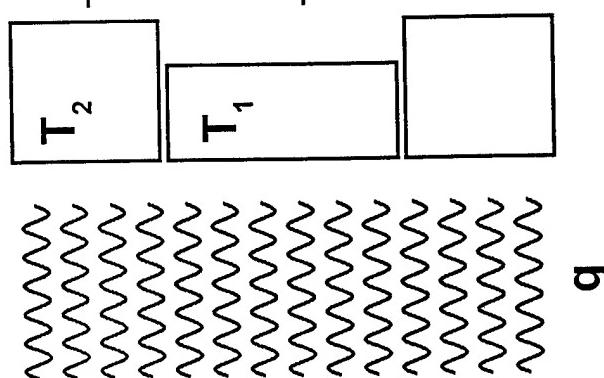
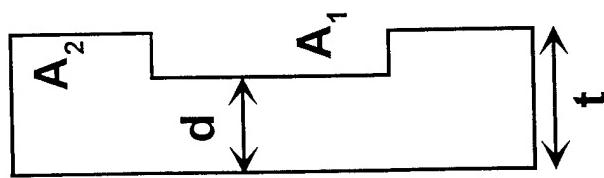


NO LATERAL HEAT CONDUCTIVITY APPROXIMATION

FLAT
BOTTOM
HOLE

NO LATERAL
CONDUCTION
APPROXIMATION

$$q = m \cdot c \cdot \Delta T$$



$$\rightarrow q_2 = \rho \cdot A_2 \cdot t \cdot c \cdot T_2$$
$$\rightarrow q_1 = \rho \cdot A_1 \cdot d \cdot c \cdot T_1$$

$$\left. \right\} -$$

$$\Delta T = \frac{Q}{\rho \cdot c} \left(\frac{1}{d} - \frac{1}{t} \right)$$

$$\Delta T = T_1 - T_2$$
$$Q = q/A$$



CONTRAST PROPERTIES

NAVAL AVIATION SYSTEMS



$$\Delta T = \frac{Q}{\rho \cdot C} \left(\frac{1}{d} - \frac{1}{t} \right)$$

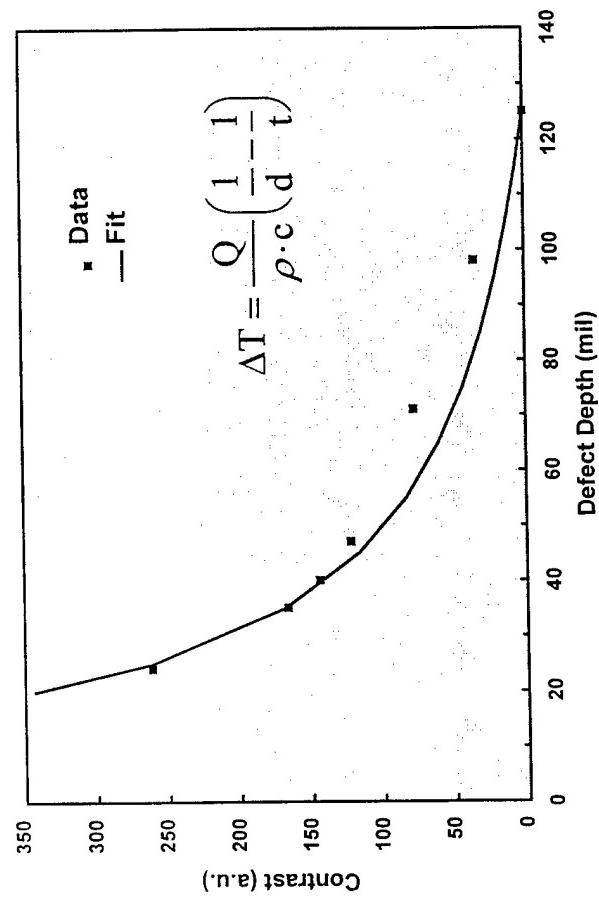
1. THE CONTRAST (ΔT) INCREASES LINEARLY WITH THE AMOUNT OF DEPOSITED ENERGY PER UNIT AREA (Q).
2. THE HIGHER THE SPECIFIC HEAT-DENSITY OF A MATERIAL ($\rho c \uparrow$) THE SMALLER THE PEAK CONTRAST ($\Delta T \downarrow$).
3. THE CLOSER THE DEFECT TO THE SURFACE ($d \rightarrow 0$) THE HIGHER THE PEAK CONTRAST ($\Delta T \rightarrow \infty$).
4. AS THE DEFECT DEPTH APPROACHES THE PANEL THICKNESS ($d \rightarrow t$) THE CONTRAST VANISHES ($\Delta T \rightarrow 0$).
5. FOR A GIVEN DEFECT DEPTH D , THE THICKER THE PANEL ($t \rightarrow \infty$) THE LARGER THE CONTRAST ($\Delta T \rightarrow Q/\rho cd$).



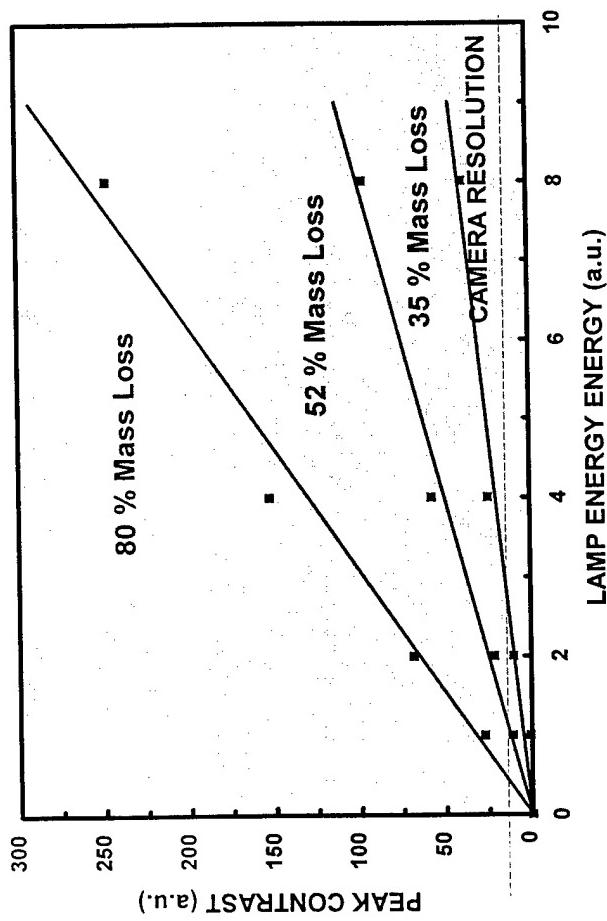
SIMPLE MODEL CORRELATION (no lateral heat flow)



CONTRAST vs DEPTH



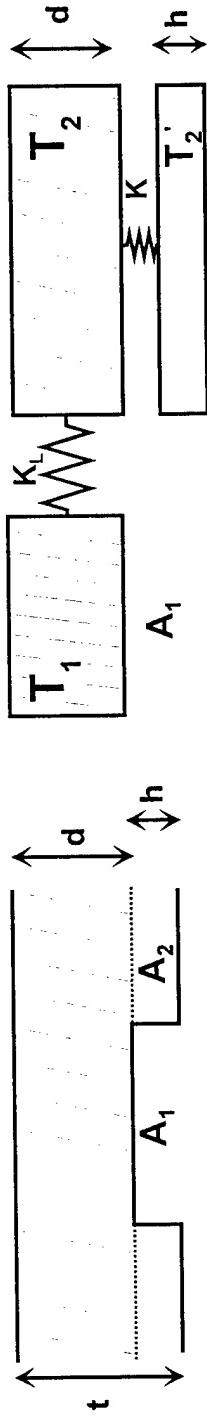
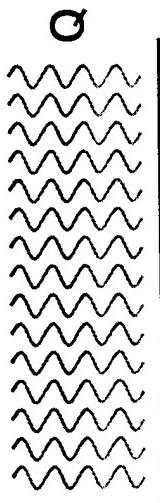
DEPTH OF RESOLUTION vs ENERGY





NAVAL AVIATION SYSTEMS

LATERAL HEAT FLOW MODEL



$$\rho \cdot A_1 \cdot d \cdot c \cdot \frac{dT_1}{dt} = k_L \cdot \frac{A_L}{R} (T_2 - T_1)$$

$$\rho \cdot A_2 \cdot d \cdot c \cdot \frac{dT_2}{dt} = k_L \cdot \frac{A_L}{R} (T_1 - T_2) + k \cdot \frac{A_2}{d+h} (T_2' - T_2)$$

k = Thermal Conductivity

k_L = Lateral Thermal Conductivity

$$\rho \cdot A_2 \cdot h \cdot c \cdot \frac{dT_2'}{dt} = k \cdot \frac{A_2}{d+h} (T_2 - T_2')$$



NAVAL AVIATION SYSTEMS

LATERAL HEAT FLOW EFFECTS



$$\Delta T(t) = \frac{Q}{\rho c \cdot d \cdot (1 - a + r)} \left(e^{-\frac{a}{d(d+h)} \frac{k}{\rho c} t} - e^{-\frac{1+r}{d(d+h)} \frac{k}{\rho c} t} \right)$$

$$t_{\max} = \frac{\rho c}{k} \frac{d \cdot t_o}{1 - a + r} \ln \frac{1 + r}{a}$$

$$\Delta T_{\max} = \frac{Q}{\rho c} \left(\frac{1}{d} - \frac{1}{t_o} \right) \cdot \left(\frac{a \cdot h}{t_o} \right)^{\frac{1}{a \cdot h} - 1}$$

$$a = \frac{k_L}{k} \frac{A_L}{A} \frac{d + h}{R}$$

$$r = \frac{d}{h}$$

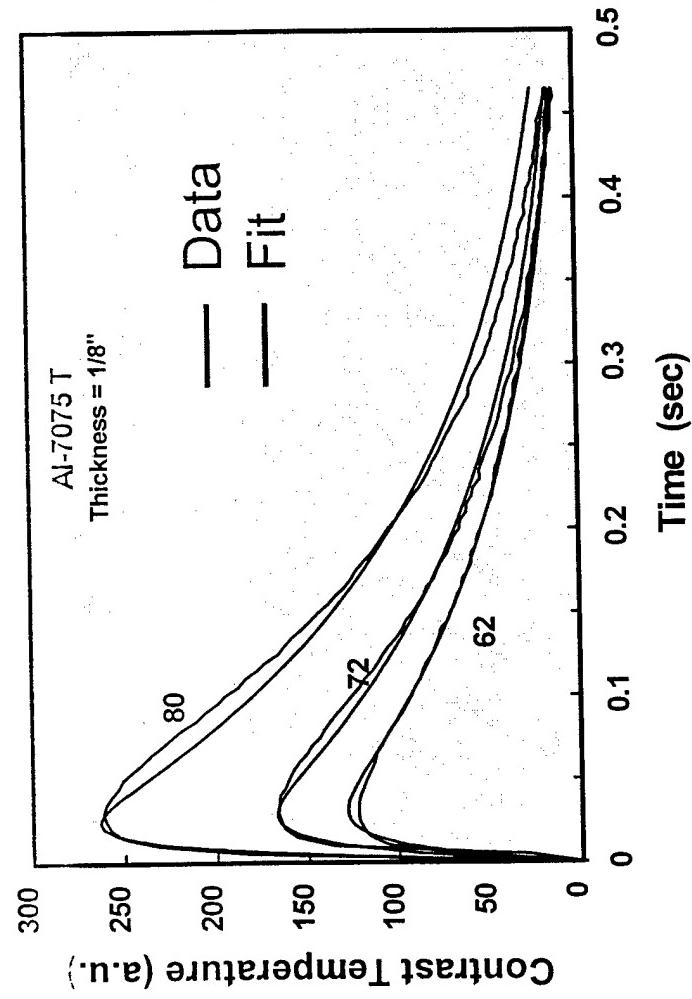
**LATERAL HEAT
FACTOR**



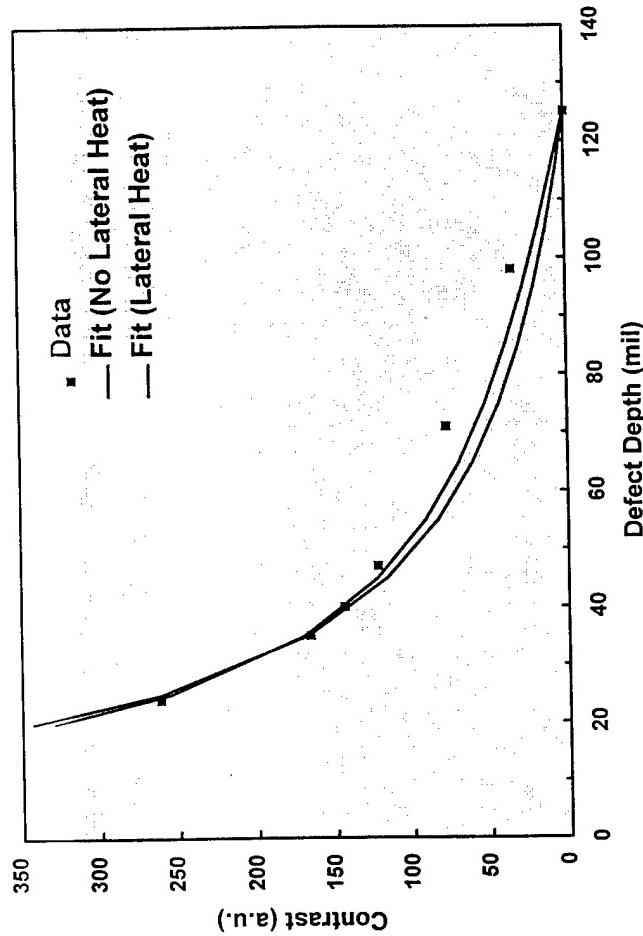
THERMAL CONTRAST PREDICTIONS



Fit of Contrats Curves



CONTRAST vs DEPTH



$$\Delta T_{\max} = \frac{Q}{\rho c \cdot d \cdot (1 - a + r)} \left(\frac{1}{d} - \frac{1}{t_o} \right) \cdot \left(\frac{a \cdot h}{t_o} \right)^{\frac{1}{a \cdot h} - 1}$$
$$\Delta T(t) = \frac{Q}{\rho c \cdot d \cdot (1 - a + r)} \left(e^{-\frac{a}{d(d+h)} \frac{k}{\rho c} t} - e^{-\frac{1+r}{d(d+h)} \frac{k}{\rho c} t} \right)$$

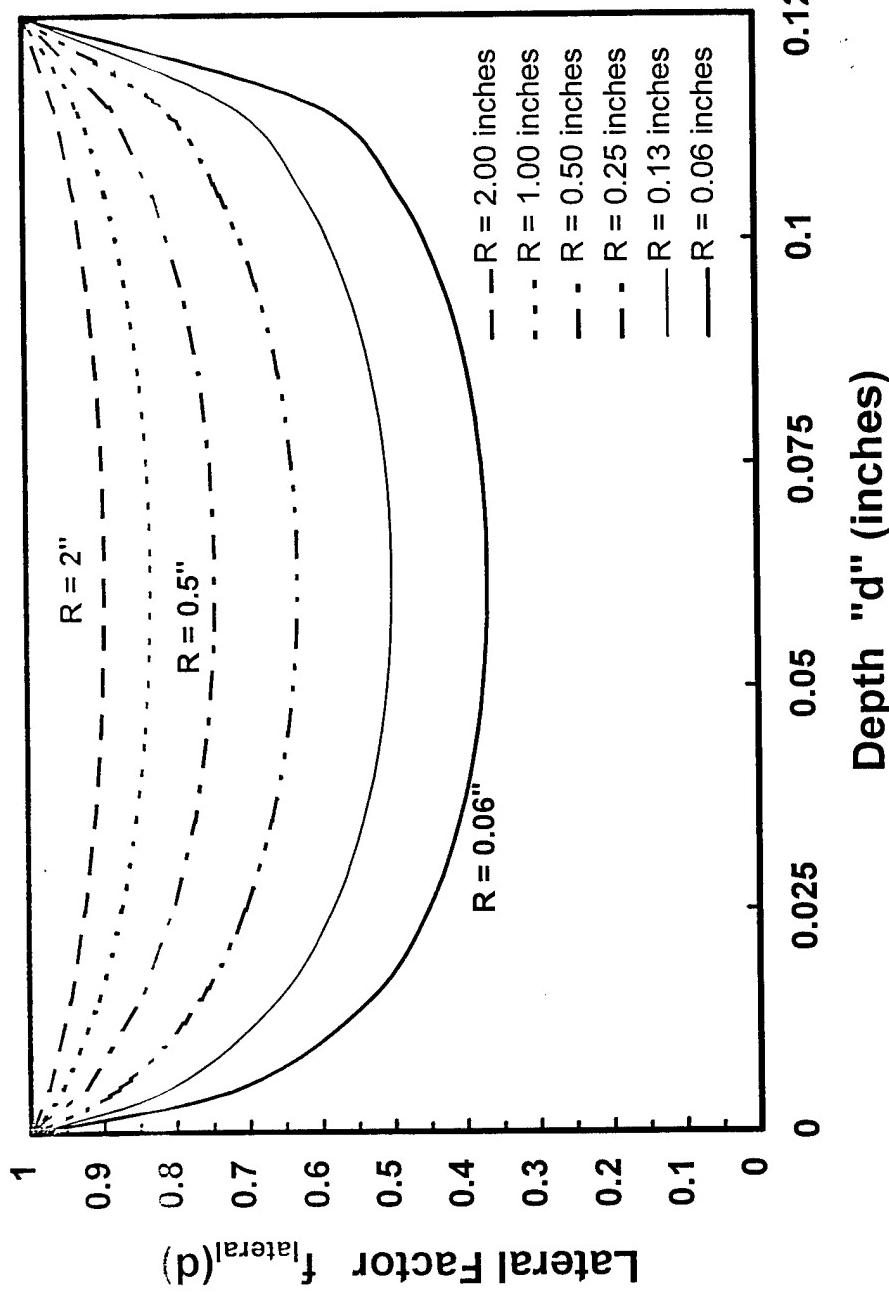


LATERAL HEAT FACTOR

(effective contact conductivity model)



Lateral Heat Factor

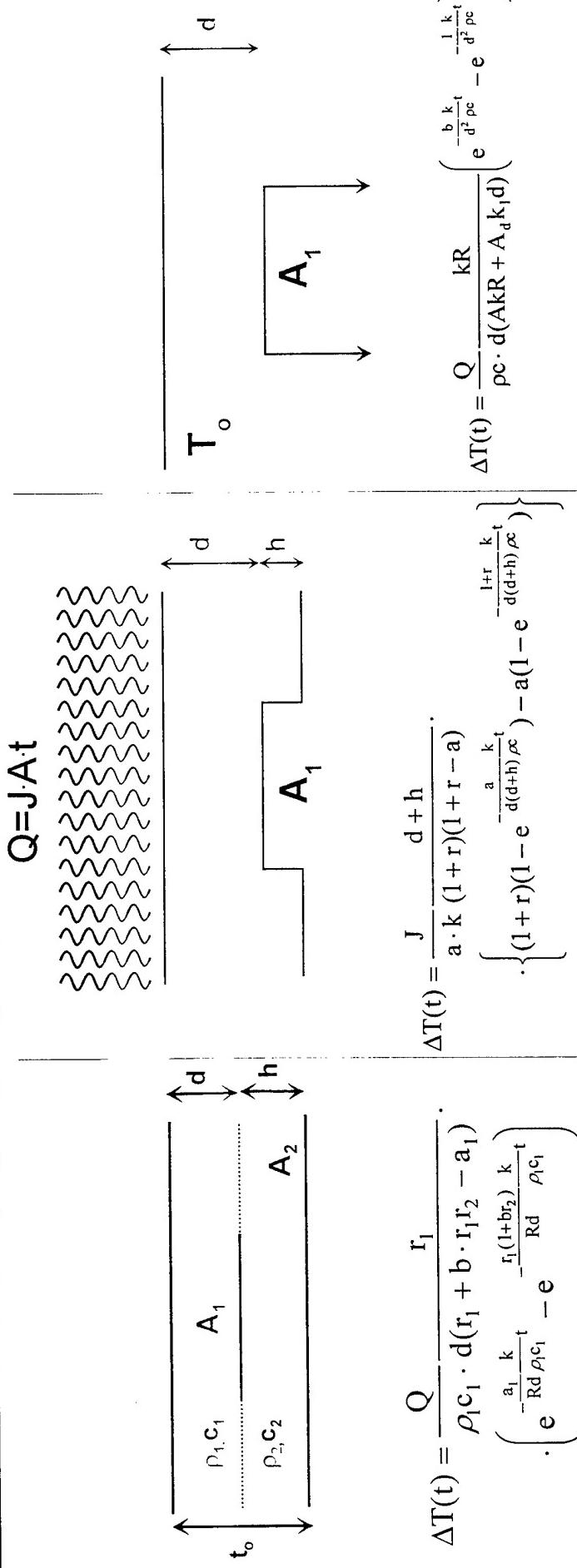


$$\Delta T_{\max} = \frac{Q}{\rho c} \left(\frac{1}{d} - \frac{1}{t_o} \right) \cdot \left(\frac{a \cdot h}{t_o} \right)^{\frac{1}{a \cdot h - 1}}$$

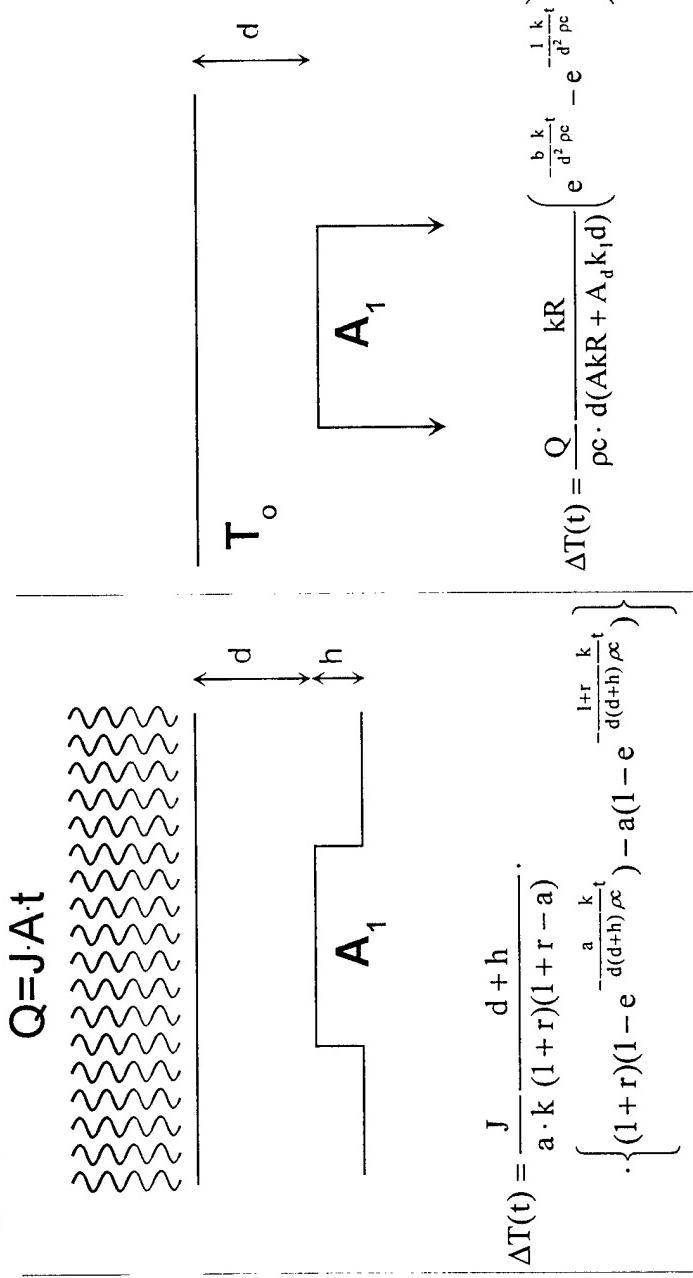


OTHER MODELING RESULTS

$$Q = J A t$$



$$\Delta T_{peak} = Q \cdot \left(\frac{1}{d} - \frac{1}{t_o} \right) \frac{\rho_2 c_2}{\rho_1 c_1} \frac{d+h}{(d\rho_1 c_1 + h\rho_2 c_2)} \cdot \left[\frac{a_1}{r_1(1+br_2)} \right]^{\frac{1}{1-\frac{a_1}{r_1(1+br_2)}}}$$



$$\Delta T_{peak} = \frac{Q}{\rho c} \frac{k R (b-1)}{d (A_d k_1 + R A_k)} \cdot [b]^{\frac{b}{1-b}}$$

$$a = \frac{k_L}{k} \frac{A_L}{A} \frac{d+h}{R} \quad r = \frac{d}{h}$$

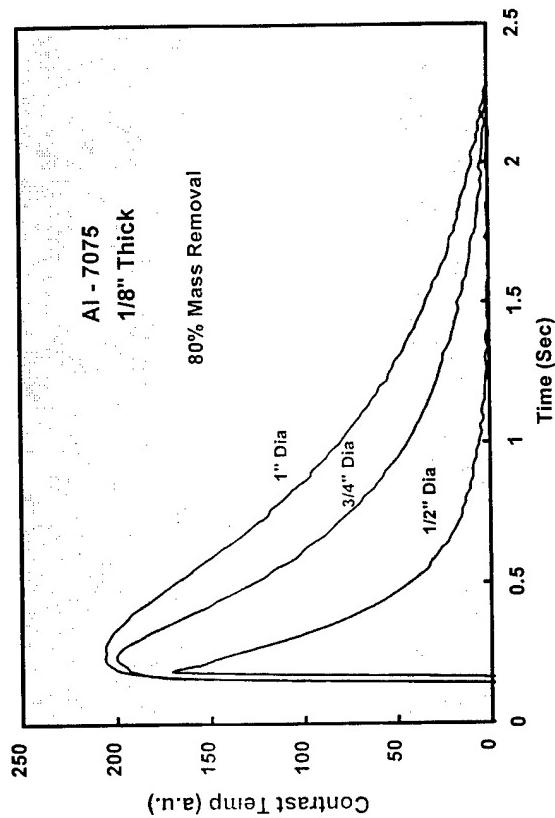
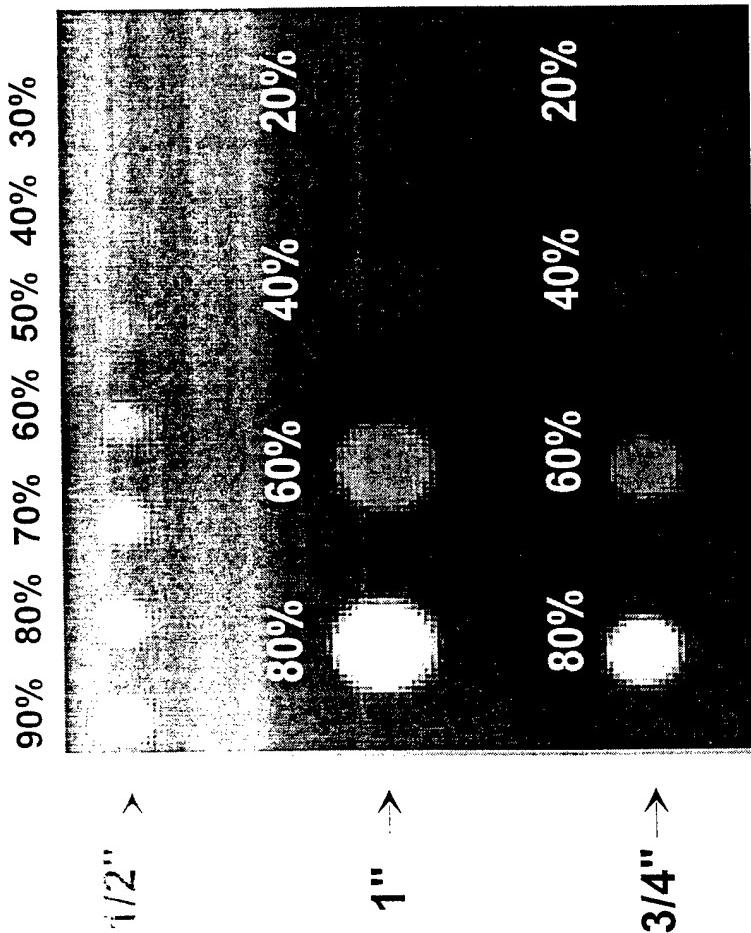
$$t_{peak} = \frac{\rho c}{k} \frac{d^2}{b-1} \ln b$$

$$a_1 = \frac{k_L}{k} \frac{A_d}{A} \quad a_2 = \frac{k_L}{k} \frac{A_h}{A} \quad b = \frac{\rho_1 c_1}{\rho_2 c_2}$$

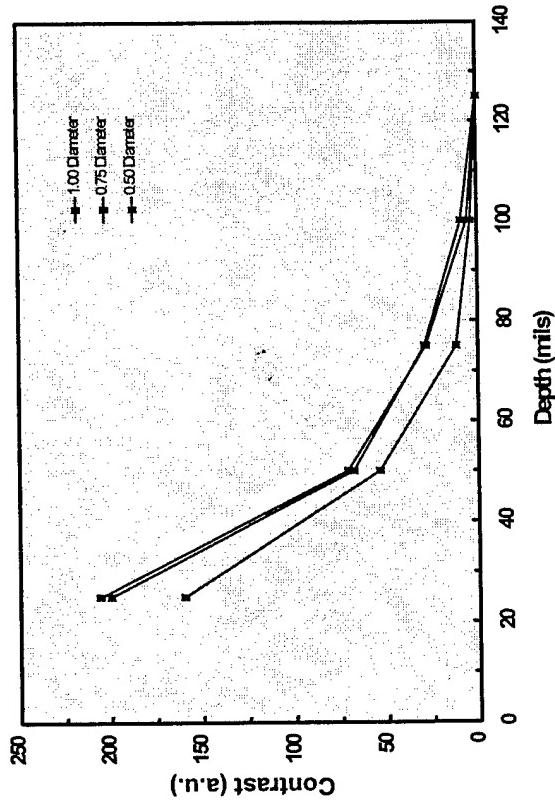
$$b = \frac{k_1}{k} \frac{A_d}{A_1} \frac{d}{R}$$



EXPERIMENTAL DATA (80% mass removal)



PEAK TEMP. VS DEPT



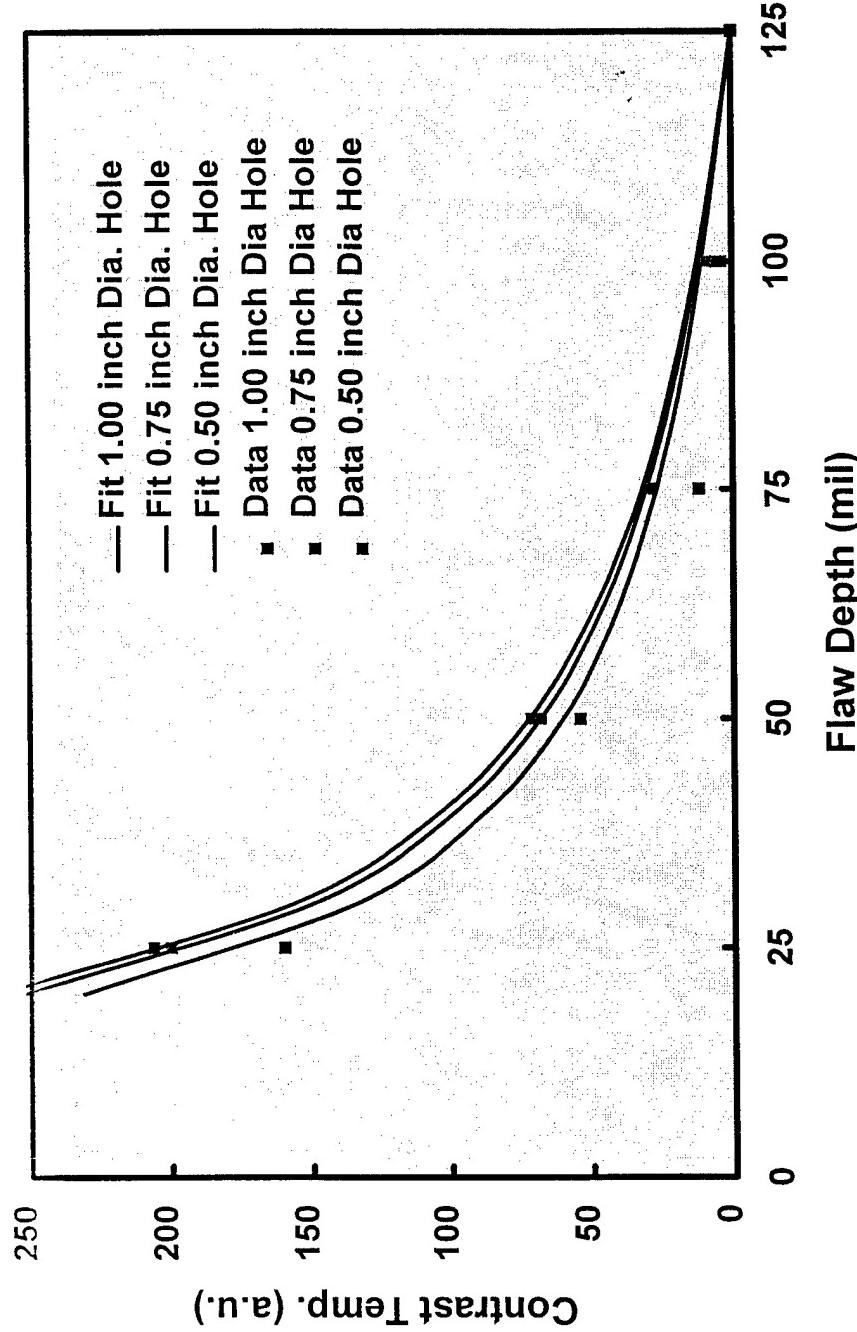
MODEL CORRELATION

(effects of defect size)



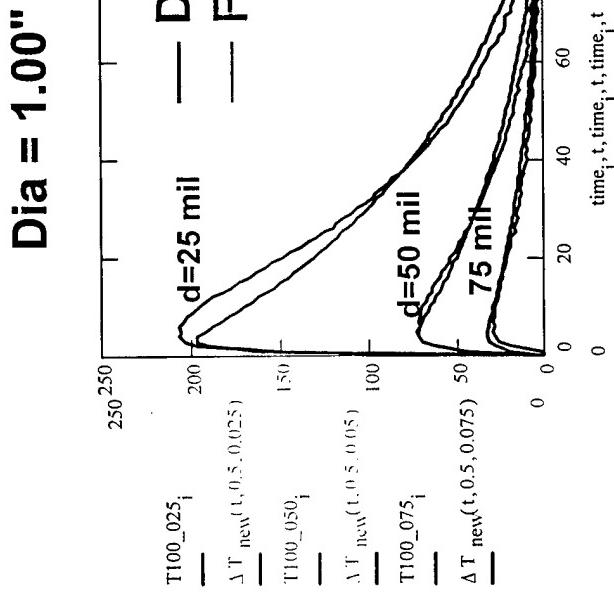
$$\Delta T_{\max} = \frac{Q}{\rho c} \left(\frac{1}{d} - \frac{1}{t_o} \right) \cdot \left(\frac{a \cdot h}{t_o} \right)^{\frac{1}{a \cdot h - 1}}$$

Effects of Radii

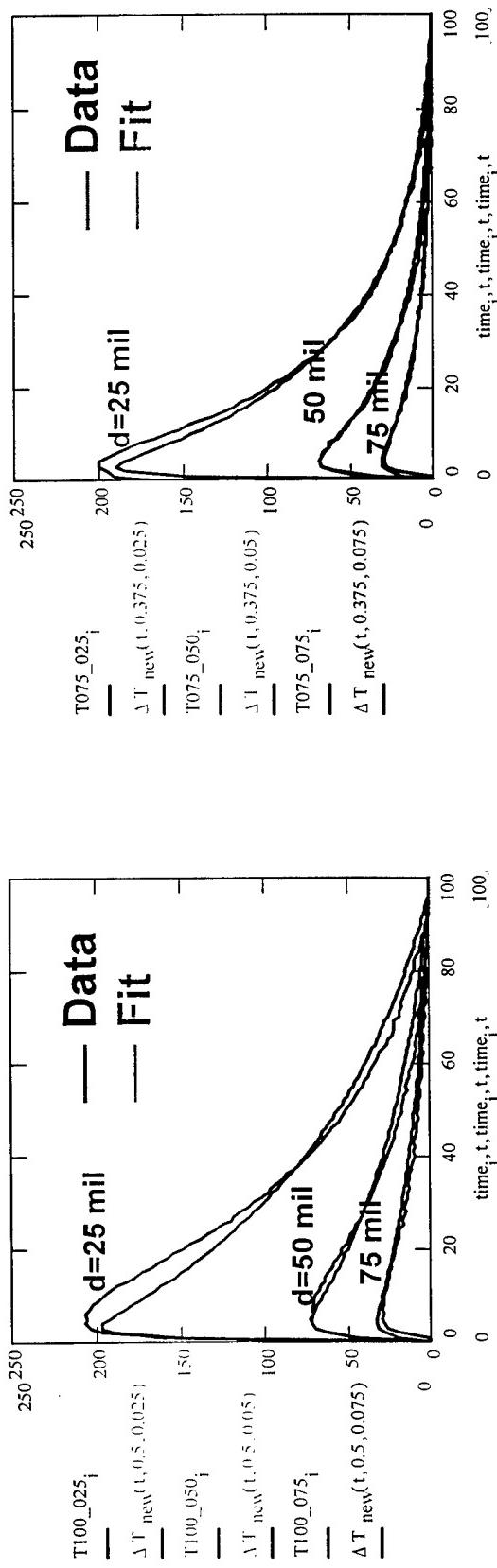




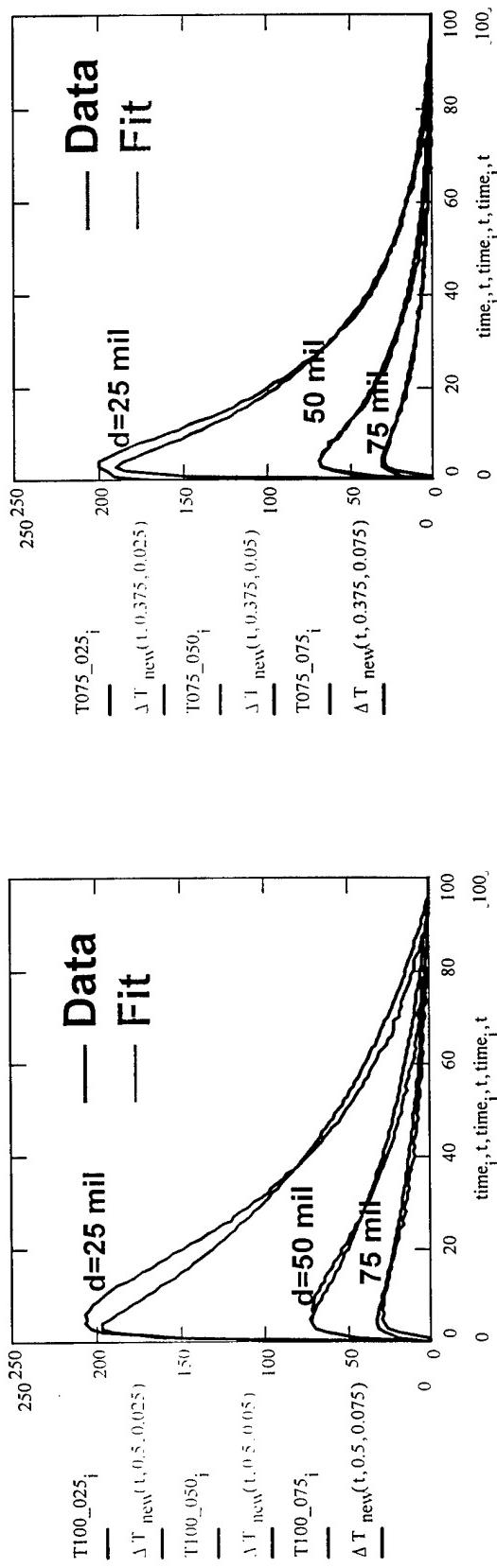
MODEL TIME-RESPONSE PREDICTIONS (varying defect sizes and locations)



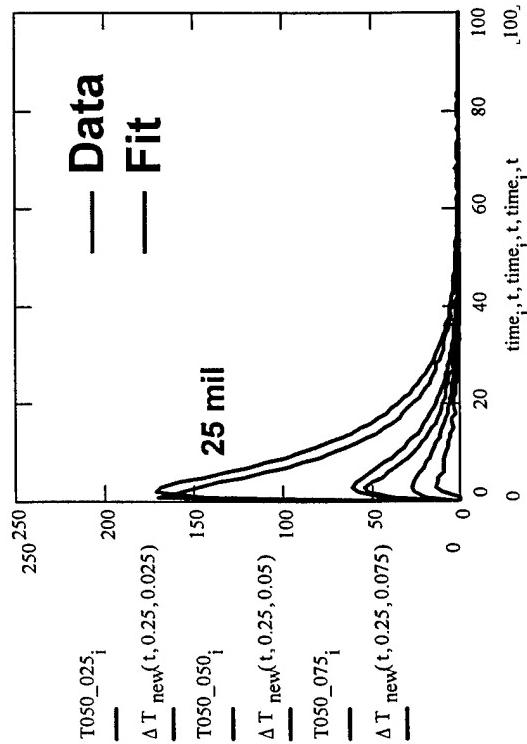
Dia = 1.00" Dia = 0.75"



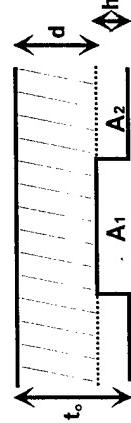
Dia = 0.75"
Dia = 1.00"



Dia = 0.50"



$$\Delta T(t) = \frac{Q}{\rho_c \cdot d \cdot (1 - a + r)} \cdot \begin{pmatrix} \frac{a}{d(d+h)\rho_c} \frac{k}{t} & -\frac{1+r}{d(d+h)\rho_c} \frac{k}{t} \\ e^{-\frac{a}{d(d+h)\rho_c} \frac{k}{t}} & -e^{-\frac{1+r}{d(d+h)\rho_c} \frac{k}{t}} \end{pmatrix}$$



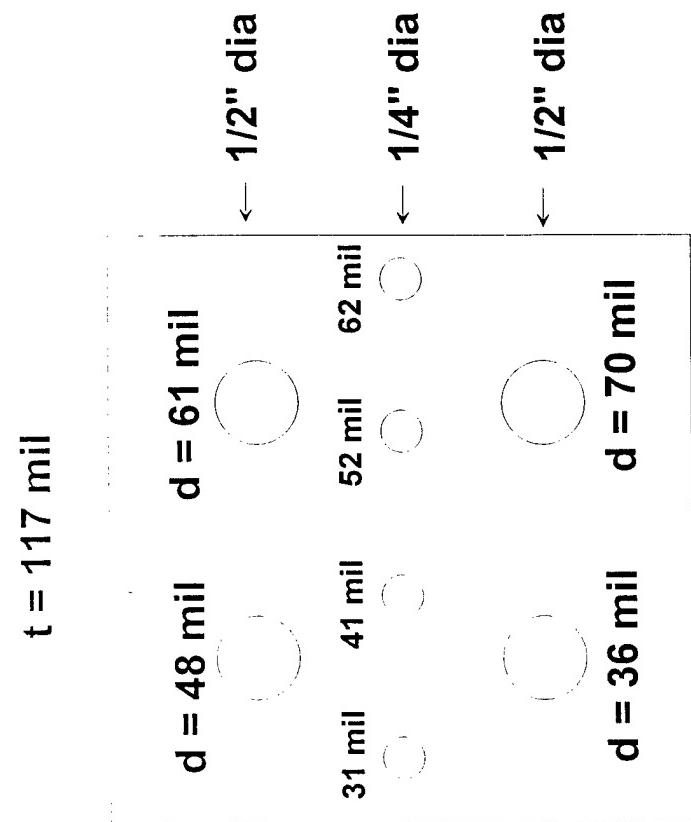
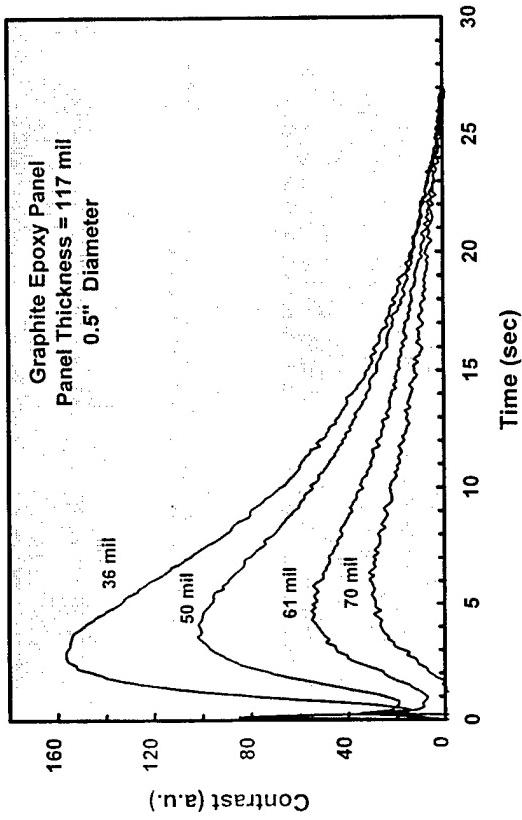


NAVAL AVIATION SYSTEMS

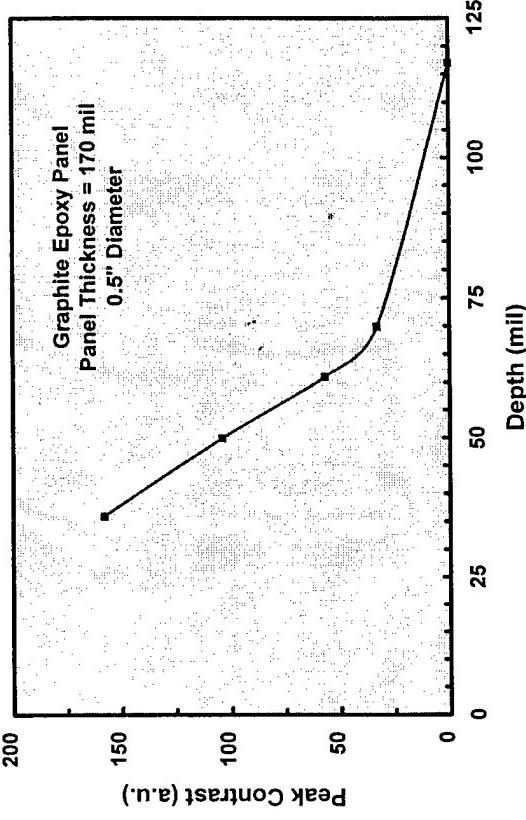
GRAPHITE EPOXY COMPOSITE PANEL



CONTRAST vs TIME

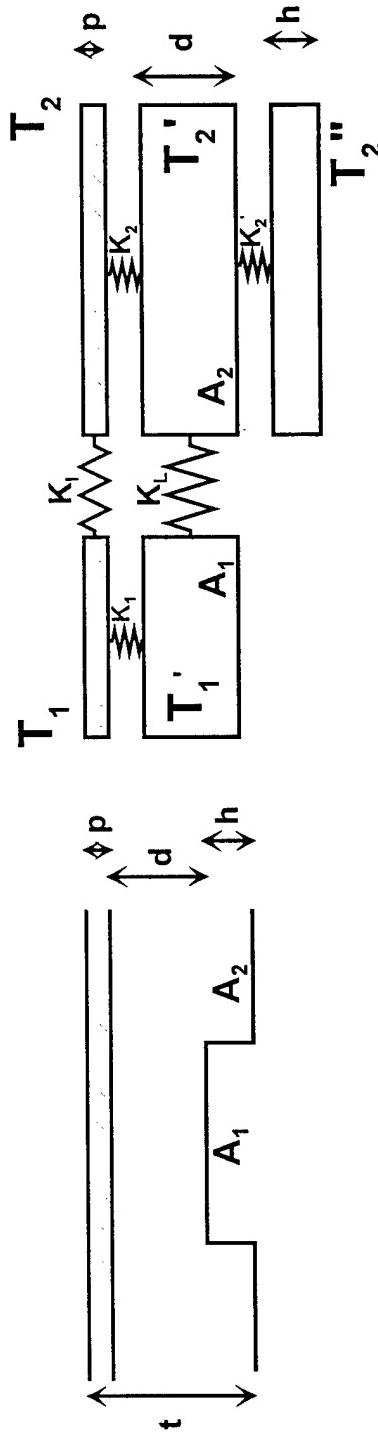
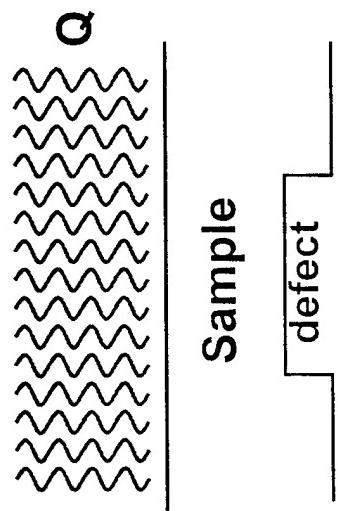
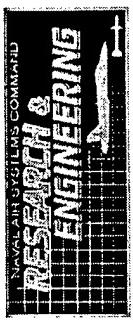


PEAK CONTRAST vs DEPTH





SIMPLE FINITE ELEMENT APPROXIMATION



$$\rho \cdot A_1 \cdot p \cdot c \cdot \frac{dT_1}{dt} = k \cdot A_1 (T'_1 - T_1) + k_L \cdot A_p (T_2 - T_1)$$

$$\rho \cdot A_2 \cdot p \cdot c \cdot \frac{dT_2}{dt} = k \cdot A_2 (T'_2 - T_2) + k_L \cdot A_p (T_1 - T_2)$$

⋮

$$\rho \cdot A_2 \cdot h \cdot c \cdot \frac{dT''_2}{dt} = k \cdot A_2 (T'_2 - T''_2)$$

k = Effective Contact Normal

Thermal Conductivity

k_L = Effective Contact Lateral

Thermal Conductivity

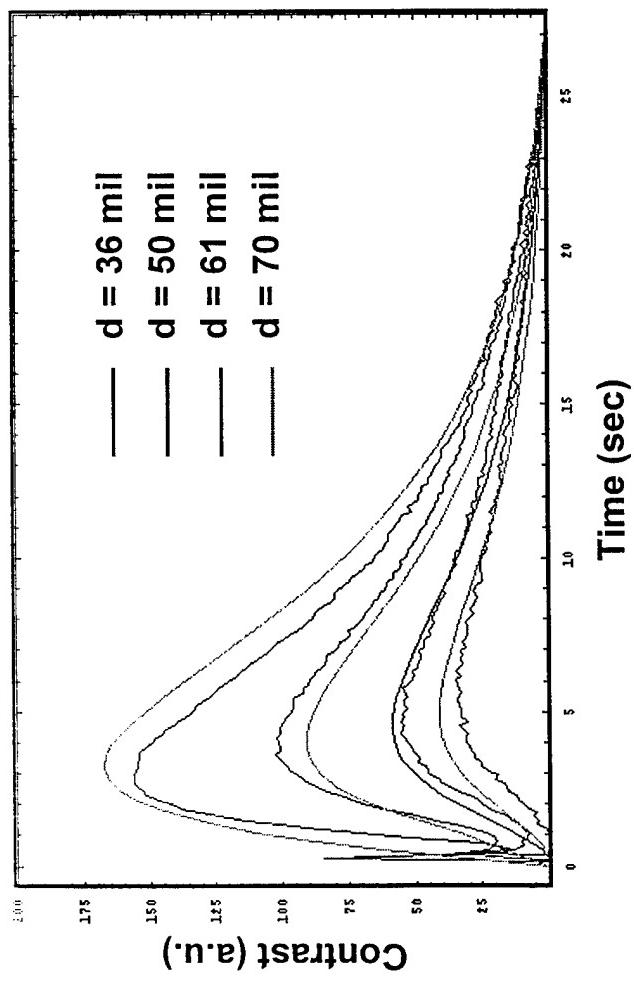


NAVAL AVIATION SYSTEMS

FITTING RESULTS



GRAPHITE EPOXY COMPOSITE
117 mil Thick



PEAK CONTRAST vs DEPTH

